



Research Paper

Evaluation of Heavy metals and selected physicochemical parameters of River Rima, Sokoto State, Nigeria

Jibrin, H.¹, Muhammad, U.², Awonuga, A.A.³, Odeniyi, O.A.¹ and Bala, G.⁴

¹Department of Fish Nutrition and Physiology, Nigerian Institute for Oceanography and Marine Research, Lagos, Nigeria

²Department of Agricultural Technology, Umaru Ali Shinkafi Polytechnic Sokoto State, Sokoto State, Nigeria

³Department of Aquaculture, Nigerian Institute for oceanography and Marine Research, Victoria Island, Lagos, Nigeria

⁴Department of Agricultural Technology, Niger State College of Agriculture, Mokwa, Nigeria

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Corresponding Author

E-mail: haliru475@yahoo.com

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Abstract

The study was conducted along the Sokoto Rima floodplain in the Wamakko area of Sokoto State, Nigeria. Water and sediment samples were collected from River Rima in Sokoto State. Sampling was conducted at three different locations along the river (Dundaye, Kwalkwalawa and Sokoto). Samples were collected twice monthly (during the first two weeks and the last two weeks) over a period of three (3) months. All samples were collected in the early hours of the day and transported to the laboratory for analysis. Four heavy metals (Zn, Pb, Cu and Cd) were analyzed. The determinations were carried at the Agricultural and Environmental Engineering Laboratory of Usmanu Danfodiyo Univeout rsity, Sokoto. A total of nine 1-L sampling bottles were used for dissolved oxygen (DO) and biological oxygen demand (BOD) analyses. Samples for DO and BOD were fixed immediately by adding 1 mL each of manganese sulphate (MnSO₄) and alkali-iodide azide solution. The concentrations of zinc (Zn), lead (Pb), copper (Cu), and cadmium (Cd) varied across the three sampling stations; Dundaye, Kwalkwalawa, and Sokoto reflecting spatial differences in potential contamination sources. The physicochemical characteristics of River Rima across the study period (June to August) reveal both temporal variations and relative stability among certain parameters, reflecting the influence of seasonal hydrological processes. Regular monitoring and control of anthropogenic activities, particularly at Dundaye should be implemented to prevent potential accumulation of heavy metals and safeguard aquatic ecosystems and public health. Effective management of River Rima should focus on controlling organic and anthropogenic pollutant inputs particularly during the early rainy season through improved waste management and runoff regulation to enhance dissolved oxygen levels and reduce biological oxygen demand.

1. Introduction

Global fish production has grown steadily over the last five decades, with food fish supply increasing at an average annual rate of 3.2%, outpacing world population growth at 1.6% (Bavitha et al., 2016). According to the Food and Agriculture Organization (FAO, 2011) of the United Nations, the contributions of fish and fish products to Nigeria's socio-economic development are significant, particularly in terms of employment creation, income generation, provision of high-quality animal protein that is easily digestible and cholesterol-free, rural development, and foreign exchange inflow through the exploitation of shrimp and smoked fish. Consequently, aquaculture is one of the fastest-growing food production sectors globally, with an annual growth rate of 9.6% over the last decade (FAO, 2011).

Water is essential for all aquatic organisms, including fish, as it supports survival, growth, excretion, and reproduction.

Water is generally considered of good quality when these functions occur efficiently and mortality is minimal, taking into account the magnitude of productivity (Ketty et al., 1987). Water sources include surface water, groundwater, and rainwater, which usually infiltrate the soil to recharge groundwater or collects in surface reservoirs.

According to Boyd and Lichtkoppler (1979), water quality is defined as the set of physicochemical and biological parameters that affect the survival, growth, and reproduction of cultured organisms, and thus demand the attention of aquaculturists. In essence, water quality encompasses all physical, chemical, and biological factors that influence the growth and welfare of cultured organisms. Different water bodies exhibit seasonal variations in chemical composition, particularly in the levels of dissolved minerals.

Dissolved minerals generally increase from lower levels during the rainy season to higher levels at the peak of the dry season (Goldman and Horne, 1983).

The term “heavy metal” is described in various ways in the literature. It is often used as a synonym for trace metals and includes both essential and nonessential metals with high atomic weight and greater density than water. Chemically, heavy metals are defined as elements that can act as electron donors, form valence ions, exchange with H^+ ions in acids, react with nonmetals to form compounds, and form alkaline oxides. Physically, they are characterized as good conductors of heat and electricity, capable of being transformed into metal plates and wires, exhibiting metallic color and lustre, and being solid under normal conditions (except for mercury) (Rainbow, 1995; Sönmez et al., 2012a; Tchounwou et al., 2012). Although heavy metals are naturally occurring in the earth's crust, most environmental contamination and human exposure result from anthropogenic activities such as mining, smelting, industrial production and use, and domestic and agricultural applications of metals and metal-containing compounds (He et al., 2005; Shallari et al., 1998).

It has been reported that metals such as cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), and zinc (Zn) are essential nutrients required for various biochemical and physiological functions. Inadequate supply of these micronutrients can result in a variety of deficiency diseases or syndromes (WHO/FAO/IAEA, 1996). The aims of this study is to evaluate the concentrations of heavy metals and selected physicochemical parameters in River Rima, Sokoto State, Nigeria, in order to assess its water quality and potential environmental and public health implications.

2. Materials and Methods

2.1 Study Area

The study was conducted along the Sokoto Rima floodplain in the Wamakko area of Sokoto State, Nigeria. Wamakko is located approximately 10 km west of Sokoto, the state capital. It lies between latitudes $13^{\circ}09' N$ and $13^{\circ}19' N$, and longitudes $5^{\circ}17' E$ and $5^{\circ}27' E$. The area is drained by River Rima, the most important perennial river in northwestern Nigeria (Adejuwon, 2018; Emeribe et al., 2019; Abdullahi et al., 2014). Its major tributaries include Rivers Bunsuru and Gagare. River Rima originates from Katsina State and flows through Zamfara and Sokoto States, where it joins the Sokoto River before eventually discharging into the River Niger in Kebbi State (Abdullahi et al., 2014; Ita, 1993).

The climate of the study area is tropical continental, characterized by a distinct wet and dry season. The rainy season occurs between June and September, while the dry season spans from October to May. Rainfall is typically intense but short-lived, often accompanied by thunderstorms at the onset of the rainy season. The mean annual rainfall is approximately 600 mm, with peak precipitation occurring in July and

August. The maximum temperature can reach up to $40^{\circ}C$ (NIMET, 2012; Wali et al., 2019).

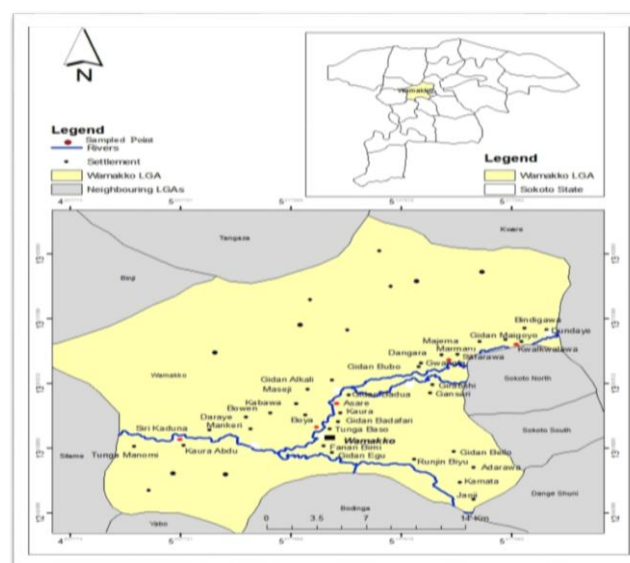


Figure1: Map of Wamakko L.G.A. showing the study area

2.2 Sample collection

Water and sediment samples were collected from River Rima in Sokoto State. Sampling was conducted at three different locations along the river (Dundaye, Kwalkwalawa and Sokoto). Samples were collected twice monthly (during the first two weeks and the last two weeks) over a period of three (3) months. All samples were collected in the early hours of the day and transported to the laboratory for analysis.

2.3 Sample Preparation

The collected samples were properly labeled and preserved for the analysis of heavy metals and physicochemical parameters.

2.4 Water Sampling

Three sampling points (A, B, and C) were selected along the river. Water samples were collected from each sampling point monthly for three months, with two samples collected per month. A total of nine 1-L sampling bottles were used for dissolved oxygen (DO) and biological oxygen demand (BOD) analyses. Samples for DO and BOD were fixed immediately by adding 1 mL each of manganese sulphate ($MnSO_4$) and alkali-iodide azide solution.

2.5 Determination of Heavy Metals

Four heavy metals (Zn, Pb, Cu and Cd) were analyzed at the Agricultural and Environmental Engineering Laboratory of Usmanu Danfodiyo University, Sokoto. Each sample digest was transferred into a 100 mL volumetric flask and diluted to the mark with distilled water. The solution was aspirated into a Buck 200 Atomic Absorption Spectrophotometer (AAS). Each metal was measured at its specific wavelength using appropriate hollow cathode lamps and standard fuel-oxidant combinations.

2.6 Determination of physicochemical parameters

The samples were analyzed at the Agricultural and Environmental Engineering Laboratory of Usmanu Danfodiyo University, Sokoto. Parameters determined included pH, total alkalinity, dissolved oxygen (DO), biological oxygen demand (BOD), and chloride using standard titration methods. Water temperature was measured in situ using a mercury-in-glass thermometer, while transparency was determined using a Secchi disc.

2.7 Determination of water temperature

Water temperature was measured using a mercury-in-glass thermometer. The thermometer was inserted into the water at a depth of approximately 5 cm and left for 2–3 minutes. The temperature was then read at the mercury meniscus and recorded in degrees Celsius (°C) (Lind, 1979).

2.8 Determination of Turbidity

Turbidity was determined using a Secchi disc. The disc was lowered vertically into the water until it disappeared from sight, and this depth was recorded as P_1 . It was then slowly raised until it reappeared, and this depth was recorded as P_2 . The average of P_1 and P_2 was taken as the measure of turbidity: $T \text{ (cm)} = \frac{1}{2} (P_1 + P_2)$ (Delince, 1992).

2.9 Determination of Dissolved Oxygen (DO)

A 250 mL bottle was carefully filled with the water sample. Subsequently, 1 mL of manganese sulphate (MnSO_4) and 1 mL of alkali-iodide azide solution were added below the surface of the water using a calibrated pipette. The sample was shaken thoroughly and transported to the laboratory on the same day. Before analysis, the sample was allowed to settle and then decanted. Two milliliters (2 mL) of concentrated phosphoric acid (H_3PO_4) were added. The sample was titrated with 0.025 M sodium thiosulphate until a pale color endpoint was reached. The volume of titrant used was recorded as the DO concentration (mg/L), based on the Winkler method (Winkler, 1888).

2.10 Determination of Biological Oxygen Demand (BOD)

Samples were collected in BOD bottles wrapped with black tape to exclude light. The samples were fixed using 1 mL of manganese sulphate (MnSO_4) and 1 mL of azide solution, shaken, and stored in the laboratory for five days. After incubation, the samples were treated with 2 mL of phosphoric acid and titrated with 0.025 M sodium thiosulphate. BOD was calculated as: $\text{BOD (mg/L)} = \frac{\text{Initial DO} - \text{final DO}}{\text{measured immediately}} \times 1000$ (measured after 5 days).

2.11 Determination of Total Alkalinity

The water samples were shaken thoroughly, and 50 mL was measured into a conical flask. Two drops each of methyl orange and phenolphthalein indicators were added. The solution was titrated with 0.05 M HCl until the color changed to orange. The titre value was recorded and used to calculate total alkalinity: $\text{Total Alkalinity (mg/L as CaCO}_3) = \text{Tv} \times 0.01 \times 1000$ (Stirling, 1985).

2.12 Determination of pH

The pH of the water samples was measured using a Jenway pH meter. The meter was calibrated using standard buffer solutions of pH 4 and pH 7. The electrode was inserted into the sample, and the pH value was recorded from the display (Stirling, 1985).

2.13 Collection and Processing of Sediment

Sediment samples were collected from three locations along River Rima and transferred into zip-lock bags. The samples were transported to the laboratory, where they were oven-dried at 65°C for three days to obtain constant dry weight. The dried samples were sieved using a 2 mm mesh sieve, transferred into sterile bags, labeled, and stored for heavy metal analysis.

2.14 Statistically analysis

Data obtained were analyzed using Analysis of Variance (ANOVA) to test for significant differences among monthly means. Duncan's Multiple Range Test (DMRT) was used for mean separation. Statistical analyses were performed using IBM SPSS version 20 software.

3. Results

3.1 Heavy Metal Concentrations of River Rima

The table 1 presents the mean concentrations (mg/L) $\pm$ standard deviation of four heavy metals (Zn, Pb, Cu, Cd) measured at three sampling stations. Superscript letters (a, b) indicate significant differences ($p < 0.05$) between stations for each metal.

The concentrations of zinc (Zn), lead (Pb), copper (Cu), and cadmium (Cd) varied across the three sampling stations; Dundaye, Kwalkwalawa, and Sokoto reflecting spatial differences in potential contamination sources. Zinc (Zn) levels were highest at Dundaye ($0.2712 \pm 0.0863 \text{ mg/L}$) and Sokoto ($0.1579 \pm 0.0282 \text{ mg/L}$), both significantly greater than Kwalkwalawa ($0.0446 \pm 0.0097 \text{ mg/L}$).

Lead (Pb) concentrations were low across all stations, with Dundaye showing $0.1823 \pm 0.1444 \text{ mg/L}$, Sokoto $0.0370 \pm 0.0281 \text{ mg/L}$, and Kwalkwalawa a negligible value ($0.0063 \pm 0.0280 \text{ mg/L}$). No significant differences were observed among stations ($p > 0.05$).

Copper (Cu) was highest at Dundaye ($0.1416 \pm 0.0213 \text{ mg/L}$), significantly exceeding Kwalkwalawa ($0.0722 \pm 0.0123 \text{ mg/L}$), whereas Sokoto ($0.0849 \pm 0.0098 \text{ mg/L}$) was not significantly different from Kwalkwalawa.

Cadmium (Cd) concentrations were low at all stations ($0.0143\text{--}0.0235 \text{ mg/L}$) with no significant differences ($p > 0.05$).

From an ecological perspective, even though the measured metals are mostly within safe limits for aquatic life, continuous monitoring is necessary.

Table 1: Mean monthly Heavy metals of River Rima

Sample station	Zn	Pb	Cu	Cd
Dundaye	0.27±0.08 ^b	0.18±0.14 ^a	0.14±0.02 ^b	0.02±0.001 ^a
Kwalkwalawa	0.04±0.00 ^a	0.06±0.02 ^a	0.07±0.01 ^a	0.02±0.004 ^a
Sokoto	0.15±0.02 ^b	0.037±0.02 ^a	0.08±0.01 ^a	0.01±0.002 ^a

Mean with similar super script along same are not significant difference (p>0.05)

Table 2: Physicochemical Parameters of River Rima

Parameters	Months		
	June	July	August
Temperature (T°C)	29.67±0.29 ^a	28.83±0.29 ^a	28.83±0.29 ^a
Hydrogen ion concentration (p ^H)	6.170±0.23 ^b	7.43±0.23 ^a	6.95±0.24 ^b
Dissolved oxygen (DO)	4.30±1.38 ^b	5.70±1.38 ^a	5.78±1.38 ^a
Biological oxygen demand (BOD)	29.817±2.93 ^a	28.32±2.93 ^b	26.617±2.93 ^c
Bicarbonate (HCO ³⁻)	2.63±0.13 ^a	2.25±0.13 ^a	2.45±0.13 ^a
Chloride (Cl ⁻)	6.35±2.50 ^c	8.42±2.50 ^b	11.48±2.50 ^a
Turbidity	9.65±0.17 ^a	9.66±0.17 ^a	9.817±0.17 ^a

Mean with similar super script along same are not significant difference (p>0.05)

fish.

4. Discussions

4.1 Heavy Metal Concentrations

Heavy metals are the core group of contaminants found in the environment and divided into essential (Fe, Cu, Zn etc.) and non-essential (Pb, Cd, Cr etc.) metals. They can neither be created nor destroyed and has direct relationship with the environmental pollution concerning their potentiality to cause toxicity in the biota (Duffus et al., 2007; Rahman et al., 2020; Sarkar et al., 2022). According to the literatures, metal bioaccumulation by fish and subsequent distribution in organs is greatly interspecific. In addition, many factors can influence metal uptake like sex, age, size, reproductive cycle, swimming pattern, feeding behavior, and geographical location (Zhao et al., 2012). Elevated Zn concentrations at Dundaye may indicate localized anthropogenic inputs such as agricultural runoff, domestic waste, or small-scale industrial activities, which is consistent with previous studies highlighting higher Zn levels in areas of increased human activity (Rainbow, 1995; He et al., 2005). The low Pb levels suggest minimal contamination, likely reflecting limited industrial or vehicular lead emissions in the studied areas, and are within acceptable limits for aquatic life (WHO, 2011; Agunbiade et al., 2026). Cu, an essential micronutrient, can be toxic at high concentrations (Rainbow, 1995). The observed Cu levels, though elevated at Dundaye, remain within typical freshwater ranges (Boyd, 2015). Cd is highly toxic even at low levels due to its bioaccumulation potential (Tchounwou et al., 2012), but the measured concentrations are below acute toxicity thresholds for

Zn and Cu, if accumulated over time, can adversely affect fish physiology and bioaccumulate in food chains, posing risks to human health through fish consumption (Sönmez et al., 2012a; He et al., 2005).

4.2 Physicochemical Parameters

Table 2 present the physicochemical characteristics of River Rima across the study period (June to August) reveal both temporal variations and relative stability among certain parameters, reflecting the influence of seasonal hydrological processes.

Water temperature ranged from 28.83 ± 0.29 to 29.67 ± 0.29 °C, with no significant variation (p > 0.05) among the months. This suggests a relatively stable thermal regime, likely due to consistent ambient climatic conditions during the rainy season. Such temperature ranges are typical of tropical freshwater systems and are suitable for aquatic biota; however, elevated temperatures may reduce oxygen solubility in water (Wetzel, 2001; Abubakar et al., 2026).

The pH values showed significant variation (p < 0.05), with July recording a slightly alkaline condition (7.43 ± 0.23) compared to mildly acidic conditions in June (6.17 ± 0.23) and near-neutral in August (6.95 ± 0.24). The increase in pH during July may be attributed to enhanced photosynthetic activity and reduced carbon dioxide concentration, while lower pH values could result from organic matter decomposition and runoff

introducing acidic substances (APHA, 2017).

Dissolved oxygen (DO) concentrations increased significantly ($p < 0.05$) from June (4.30 ± 1.38 mg/L) to July (5.70 ± 1.38 mg/L) and August (5.78 ± 1.38 mg/L). This improvement in DO levels may be linked to increased water flow and aeration during peak rainfall. Higher DO levels are generally indicative of better water quality and support aquatic life (Chapman, 1996). Conversely, the relatively low DO in June suggest higher organic load or reduced flow conditions.

Biological oxygen demand (BOD) exhibited a significant decreasing trend ($p < 0.05$) from June (29.82 ± 2.93 mg/L) to August (26.62 ± 2.93 mg/L). High BOD values indicate substantial organic pollution, likely from runoff carrying organic wastes into the river at the onset of rains. The gradual reduction suggests dilution effects and improved self-purification capacity of the river system over time (Metcalf & Eddy, 2003). Bicarbonate (HCO_3^-) concentrations showed no significant variation ($p > 0.05$), indicating stable buffering capacity of the river system. This stability helps maintain pH balance and is essential for aquatic ecosystem sustainability (Hem, 1985). Chloride (Cl^-) concentrations increased significantly ($p < 0.05$) from June (6.35 ± 2.50 mg/L) to August (11.48 ± 2.50 mg/L). This rise may be associated with increased surface runoff, anthropogenic inputs, or evaporation effects concentrating dissolved ions. Elevated chloride levels can indicate pollution from domestic or agricultural sources (WHO, 2017).

Turbidity values remained high but showed no significant difference ($p > 0.05$) across the months, ranging from 9.65 ± 0.17 to 9.82 ± 0.17 NTU. Persistent turbidity during the study period is likely due to continuous inflow of suspended particles from runoff and erosion during the rainy season. High turbidity can limit light penetration, affecting photosynthesis and aquatic productivity (Davies-Colley & Smith, 2001).

5. Conclusion

The data indicate spatial variability in heavy metal contamination, with Dundaye consistently showing higher Zn and Cu concentrations. This suggests localized anthropogenic influence, whereas Kwalkwalawa shows generally lower metal levels, indicating relatively cleaner water conditions. Pb and Cd levels were low at all sites, suggesting minimal environmental contamination from these metals in the study area. The results indicate that River Rima experiences moderate organic pollution, particularly at the onset of the rainy season, as evidenced by high BOD and lower DO in June. However, water quality appears to improve progressively towards August due to dilution and increased flow. The stability in temperature, bicarbonate, and turbidity suggests consistent environmental conditions, while variations in pH, DO, BOD, and chloride reflect seasonal influences and possible anthropogenic inputs.

6. Statement of Declarations

Ethical Approval: Not applicable.

Conflict of Interest: The authors in this article declare that they have no known competing financial interests or personal relationship that could have appeared to influence the work reported in this article.

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References

- Abdullahi, S.A. et al. (2014). Assessment of water availability in the Sokoto Rima River Basin. *Resources and Environment*, 4(4): 220-233.
- Abubakar, MMagami, I.M., Salawu, A., Muhammad, U. (2026). Effects of Seasons on Some Physical Water Quality Parameters in Bakolori Reservoir. *Journal of Fisheries and Zoological Sciences*, 1(2), 1-4. <https://doi.org/10.65385/JFZS0001>
- Adejuwon, J.O. (2018). Assessment of the Changing Pattern in Maize Cultivation in Sokoto-Rima River Basin, Nigeria. *Journal of Applied Sciences and Environmental Management*, 22(9): 1433.
- Agunbiade, R.O., Edward, J.B., Odeyemi, D.F., Adegbola, M.A., Babalola, T.M. (2026). Environmental Impact of Leachate Pollution on Groundwater Sources in Ikere Metropolis, Ekiti State, Nigeria. *Journal of Fisheries and Zoological Sciences*, 1(2), 5-9. <https://doi.org/10.65385/JFZS0002>.
- APHA (2017). *Standard Methods for the Examination of Water and Wastewater* (23rd ed.). American Public Health Association, Washington, DC.
- Boyd, C.E. (2015). *Water Quality: An Introduction*. Springer.
- Chapman, D. (1996). *Water Quality Assessments: A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring*. UNESCO/WHO/UNEP.
- Davies-Colley, R. J., & Smith, D. G. (2001). Turbidity, suspended sediment, and water clarity: A review. *Journal of the American Water Resources Association*, 37(5), 1085–1101.
- Delince, G. (1992). Measurement of water temperature, Recirculation Aquaculture System NRAC No. 01-002.
- Dautremepuits, C.; Paris-Palacios, S.; Betoulle, S.; Vernet, G.: Modulation in hepatic and head kidney parameters of carp (*Cyprinus carpio* L.) induced by copper and chitosan. *Comp Biochem Physiol C Toxicol Pharmacol*. 2004, 137, 325-33.
- Duffus, J. H., Nordberg, M., & Templeton, D. M. (2007). Glossary of terms used in toxicology (IUPAC Recommendations 2007). *Pure and Applied Chemistry*, 79(7), 1153–1344.
- Emeribe, C.N., E.T. Ogbomida, J.O. Enoma-Calus. Climatic Variability and Estimation of Supplementary Irrigation Water Needs of Selected Food Crops in the Sokoto-Rima River Basin, Nigeria. *Nigerian Journal of*

-
- Environmental Sciences and Technology, 2019, 3(1): 86-104.
- He, Z.L., Yang, X.E., & Stoffella, P.J. (2005). Trace elements in agroecosystems and impacts on the environment. *Journal of Trace Elements in Medicine and Biology*, 19(2-3), 125-140.
- Hem, J. D. (1985). *Study and Interpretation of the Chemical Characteristics of Natural Water* (3rd ed.). US Geological Survey.
- Ita, E.O. (1993). *Inland Fishery Resources of Nigeria*. CIFA Occasional Paper No. 2 EAO, Rome Italy. 1-120.
- Metcalf & Eddy (2003). *Wastewater Engineering: Treatment and Reuse* (4th ed.). McGraw-Hill.
- NIMET (2012). *Climate review: Nigerian Meteorological Agency*.
- Rahman, M. M., & Hassan, M. M. (2020). The amount of selected heavy metals in water, sediments and fish species from the Rupsha River, Khulna, Bangladesh. *Asian Journal of Fisheries and Aquatic Research*, 6(2), 1-9.
- Rainbow, P.S. (1995). Biomonitoring of heavy metals in the marine environment. *Marine Pollution Bulletin*, 31(4-12), 321-326.
- Sarkar, A., Das, S., & Bhowmick, A. (2022). Effects of heavy metals on fish physiology – A review. *Chemosphere*, 300, 134519. doi.org
- Shallari, S., Schwartz, C., Hasko, A., & Morel, J.L. (1998). Heavy metal contamination in urban areas. *Science of the Total Environment*, 215(1-2), 1-20.
- Sönmez, F., et al. (2012a). Heavy metals and aquatic systems: Assessment and management. *Environmental Monitoring and Assessment*, 184(4), 2341-2353.
- Stirling, H. P. (Ed.). (1986). *Chemical and Biological Methods of Water Analysis for Aquaculturists*. University of Stirling, Institute of Aquaculture, Stirling, UK.
- Tchounwou, P.B., et al. (2012). Heavy metal toxicity and the environment. *Molecular, Clinical and Environmental Toxicology*, 101, 133-164.
- Wali, S.U., et al. (2019). Hydrochemical characterization of shallow and deep groundwater in Basement Complex areas of southern Kebbi State, Sokoto Basin, Nigeria. *Applied Water Science*, 9(169): 1-36.
- Wetzel, R. G. (2001). *Limnology: Lake and River Ecosystems* (3rd ed.). Academic Press.
- WHO (2017). *Guidelines for Drinking-water Quality* (4th ed.). World Health Organization.
- WHO/FAO/IAEA (1996). *Trace elements in human nutrition and health*. Geneva: World Health Organization.
- Winkler, L. W. (1888). Die Bestimmung des im Wasser gelösten Sauerstoffes. *Berichte der Deutschen Chemischen Gesellschaft*, 21(2), 2843-2854.
- Zhao S., Feng C., Quan W., Chen X., Niu J., Shen Z. (2012). Role of living environments in the accumulation characteristics of heavy metals in fishes and crabs in the Yangtze River Estuary, China;64(6):1163-1171. doi: 10.1016/j.marpolbul.2012.03.023.